A FIELD TEST FOR COMPARISON OF E-BIKES AND CONVENTIONAL BICYCLES IN TRAFFIC

Jan-Philipp Sander, corresponding author
Technische Universitaet Berlin
Faculty V – Mechanical Engineering and Transport Systems
Institute of Land and Sea Transport Systems
Chair of Naturalistic Driving Observation for Energetic Optimisation and Accident Avoidance
Secretariat TIB13
Gustav-Meyer-Allee 25
D-13355 Berlin
Phone +49 (0)30 314-72997
Fax +49 (0)30 314-72505
sander@mail.tu-berlin.de

Prof. Dr. rer. nat. Stefanie Marker
Technische Universitaet Berlin
Faculty V – Mechanical Engineering and Transport Systems
Institute of Land and Sea Transport Systems
Chair of Naturalistic Driving Observation for Energetic Optimisation and Accident Avoidance
Secretariat TIB13
Gustav-Meyer-Allee 25
D-13355 Berlin
Phone +49 (0)30 314-72981
Fax +49 (0)30 314-72505
stefanie.marker@tu-berlin.de

Words in abstract: 234
Words in text body: 5212
Words in references: 331
Total word count: 5777 + 5x250 = 7027
Number of figures: 3
Number of tables: 2

Submission date: 2014-11-14

ABSTRACT

During the last years, the number of electric-assist and electric-power bicycles has increased continuously. Whether this causes risks in mixed traffic with conventional bicycles or existing cycling infrastructure is appropriate for the use of e-bikes, is part of current research.

To determine differences in the use of e-bikes and conventional bicycles in traffic, short-term field tests were conducted. An electric-assist bike was equipped with a measuring system, consisting of four cameras, two microphones, an acceleration sensor and a rate sensor. The position is determined by GPS. 52 subjects rode on a course through downtown Berlin twice. In one of the circuits, the motor was turned off to emulate a conventional bicycle. The subjects filled out a questionnaire.

The motor assisted average speed was about 3 km/h (1.9 mph) higher than the speed without motor assistance. For fast riders, the speed difference was lower than for slow riders. Accordingly, the number of overtaking maneuvers increased by 9% through the motor assistance for fast riders, and by 113% for the slow riders.

Another goal was to apply methods of naturalistic driving studies on bicycles. The used measuring equipment and method was sufficient for generating lots of usable data on cyclists' behavior in traffic. For strong naturalistic conditions, the methodology reveals some flaws: The equipment is not protected from weather influences and theft. It is therefore usable in a field test environment, but not in everyday activities.

Keywords: naturalistic cycling, naturalistic driving, pedelec, e-bike, bicycle, cycling infrastructure, safety, ndo, fot

INTRODUCTION

A pedelec, portmanteau of pedal-electric cycle, is the electric-assist sub-type of e-bikes. In Germany, as in many countries, they legally qualify as bicycles. The motor only supports the rider while pedaling. Above 25 km/h (16 mph), the motor assistance stops. The maximum continuous rated power is limited to 250 W.

In Germany, riding bicycles is an important mode of transportation. The number of e-bikes in road traffic increased significantly over the last years. According to the ZIV, the German association of the bike industry, the sales volume of e-bikes, especially pedelecs with a ratio of 95% to 98% among them, increased from 150,000 units in 2009 to 380,000 units in 2012. The market share of e-bikes in Germany was 10% in 2012. (*1*)

Currently, differences between bicycle usage and pedelecs usage, as well as their challenging interaction, have hardly been researched. It has to be determined if current standards for bicycle infrastructure and the infrastructure itself have to be modified for usage by pedelecs.

For infrastructure analysis from the cyclists' point of view, it is useful to observe them in their everyday business. In naturalistic cycling studies, the cyclist ideally rides an instrumented bicycle on his own routes and in his own manner, forgetting about being observed by cameras or other sensors. Later, the researcher can analyze the occurrences from the data.

This study aims to work out differences between bicycles and pedelecs in urban traffic. It focuses on different speeds reached under different conditions, and cyclists' interactions with other road users, simultaneously testing the capability of the measuring system.

STATE OF RESEARCH

The behavior of cyclists has been analyzed in numerous studies, also with naturalistic driving methods. Regarding e-bike riders is a new field of research. For the few studies conducted up to now, mosty just preliminary results are published.

For an Australian pilot study, six subjects, instrumented with helmet mounted cameras, collected 46 hours of video. Additionally, a survey was filled out, as well as a weekly report. The goal to adapt naturalistic driving methods to bicycles was reached. 36 identified occurrences were ranked as near-collisions according to modified criteria from the "100-car study". (2) (3)

The Australian Monash University Accident Research Center investigated risks of accidents or near-accidents for on-road bicycle commuters. 13 subjects recorded twelve hours of video each with a helmet mounted camera. Frequency of head checks, reactions and maneuvers were analyzed. Out of the 54 incidents, two collisions and six near-collisions were identified. 70.3% of the incidents occurred at intersections. In 87% of the cases, the driver of the vehicle was judged at fault. For the analysis of the video data, modified criteria of the Virginia Technology Transport Institute 100-car study and codes from the VicRoads Definitions for Classifying Accidents (DCA) were used. (4)

In the greater Stockholm area, 16 subjects rode on instrumented bicycles along 17 routes, preferably on cycling infrastructure and respecting traffic rules. Risk factors and accessibility problems were identified from speed and position data, video and diaries. 240 hours were recorded in 438 rides. 13% of the time was identified as delay, calculated as the difference between the used time for the trip and the time needed if assumed that the route was driven in the rider's comfort speed. Of 506 identified problems, 220 were categorized as safety relevant. Conflicts between bicycles and vehicles arose mainly at intersections, overtaking conflicts between cyclists on two-directional bike paths. The intersection and bus stop design was a main reason for security problems, as were uneven road surface, curbs, sharp turns and improperly designed lane widths. Temporary problems were mainly caused by improperly parked vehicles, pedestrians and items on the cycle lanes. (*5*)

For the BikeSAFER study conducted by Chalmers University of Technology in Gothenburg, Sweden, a bicycle was equipped with camera, GPS logger, inertia measuring units, break pressure sensors and a speed meter. An incident button was installed to mark relevant situations in the collected data. Several subjects used the bicycle for two weeks each. The use of driving data was strongly encouraged for identification of safety relevant situations by the researchers. Also, the response of the cyclist through the incident button proved to be useful for identifying critical situations. (6)

Research of BikeSAFER was continued with instrumented e-bikes in the eBikeSAFE project. The objective was to examine the behavior of e-bike users in traffic and whether critical situations occur more often or differently compared to conventional bicycles. The measuring equipment from the previous study was extended by pedal and motor current sensors. No detailed results have been published yet. (*7*)

Two German Universities at Chemnitz and Munich, together with UDV (German Insurers Accident Research), studied 30 subjects riding on conventional bicycles, 50 on pedelecs, and 10 on other e-bikes, to determine how and by whom e-bikes are used. Obtained speeds and safety critical events are regarded. The subjects use their own vehicles, equipped with a GPS logger, altimeter, speedometer and two cameras. No detailed results had been published when this paper was written. (8)

The SWOV Institute for Road Safety Research in the Netherlands, together with Delft University of Technology, conducted a field study regarding the safety of elderly cyclists. Regular cyclists were asked to ride a route of 3.5 km (2.2 mi) length once on a bicycle and once on an e-bike. Driving data, heart frequency, mental workload and geographic position were recorded. Half of the 58 valid data sets were of cyclists between 30 and 45 years of age, the other ones above 65. Bicycle and pedelec were equipped with speed meter, steering angle sensor, GPS, a camera filming the cyclist, and an accelerometer/gyroscope/compass unit. The subjects wore a helmet camera, a wrist band for measuring heart frequency, and a device for a peripheral detection task. The route included residential areas, an overpass and a remote bicycle path. Differences in speed were found between pedelec and bicycle as well as between the two age groups. There was no significant difference in reaction time, identified by PDT, between e-bike and bicycle. The mental workload was higher for the elder subjects. It is assumed that the mental workload influences speed choice as well as physical condition and skill. (*9)*

MATERIALS AND METHODS

In the field study conducted by TU Berlin, the behavior of cyclists on pedelecs and conventional bicycles in traffic is examined and compared. A pedelec was equipped with a measuring system, consisting of a GPS data logger, an acceleration sensor and microphones. Three cameras were directed to the front, left side and back, providing an almost-panorama view, another camera filmed the rider. With the motor of the pedelec turned off, it was used as a conventional bicycle. Data sets of 50 subjects were collected, each containing one ride with motor aid and one without.

The route represents a typical trip through downtown Berlin along bicycle paths and lanes in good and poor condition and on-road. The data allows to compare different types of cycling infrastructure. With the video data, interactions between the subject and other road users can be analyzed. The questionnaire collects demographic data and cycling practice information. Furthermore, the subjects are asked about their impressions during the rides, focusing on critical situations.

Test Vehicle and Measuring Equipment

The pedelec is depicted in fig. 1. It is equipped with 9-speed derailleur gears. The frame has a trekking geometry with a monotube frame. Rider's position is upright. The weight, including battery, is 23.5 kg (51.7 lb) and 27.3 kg (60 lb) with the measuring system. The motor is mounted on the bottom bracket.

The measuring system consists of a GPS receiver, a 10 Hz data logger and audio/video recording devices. (*10*) Speed is automatically derived from GPS data by the logger. This readily-available solution avoids problems with synchronization of video and data streams, often mentioned in other studies. (*6, page 289*) (*10, page 6*). An additional acceleration sensor was mounted on the luggage carrier.

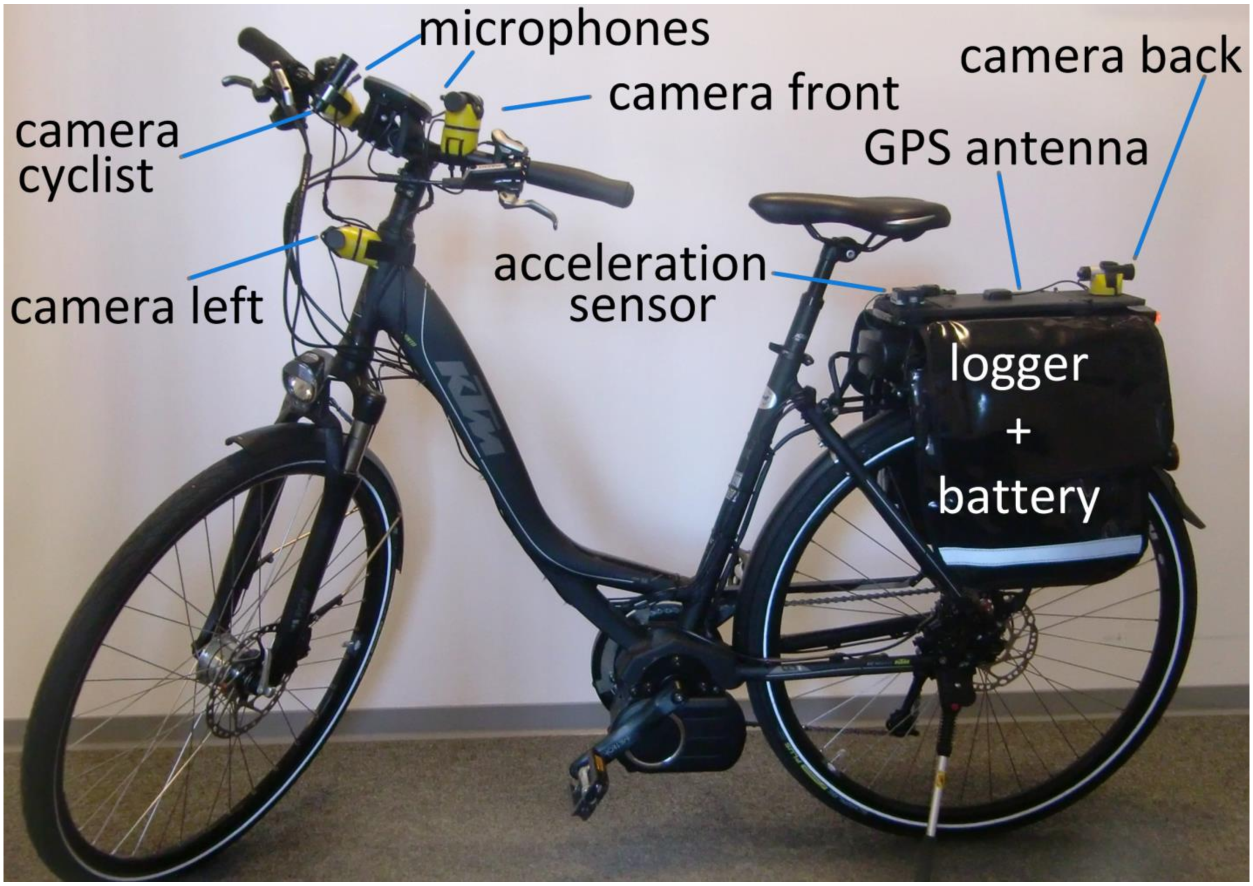

FIGURE 1 Pedelec equipped with measuring system.

Course

A route of 7.5 km (4.7 mi) was set. The ride starts on cobbled pavement, followed by a roundabout with a separate bicycle lane. Other parts of the route contain bicycle lanes, bicycle paths in different qualities and on-road sections. Two inclines and declines occur. The length of the route was chosen to make sure that it can be managed twice even by unexercised subjects. The route is exemplary for a typical ride on major roads through several districts in central Berlin.

Test Subjects

For insurance reasons, only TU Berlin members were recruited as subjects. The non-representative group consists of 43 males and 9 females. 73% of the subjects were between 22 and 30 years of age, the others older. Data acquired from two male subjects could not be used for the analysis. 13 subjects have ridden an e-bike before, but none frequently. All others rode an e-bike for the first time.

Questionnaire

The questionnaire contains demographic questions as well as questions about bicycle usage in general. After each of the two test rides, the subjects were asked about their impressions on the ride. They were asked to grade their level of exertion, and should reflect special incidents, like conflicts with other traffic participants. It was also asked for the situation on the roads and their subjective personal safety. After the motor assisted ride, additional specific questions were asked, like the motor assistance usefulness.

The subjects were also asked if they felt to have been influenced by the measuring equipment in a physical or psychological manner, and if other problems not asked about before occurred. These questions can help to identify whether the subjects behaved in a natural manner and to improve future studies.

Execution of the Test Rides

After filling the first part of the questionnaire, the subjects could get in touch with the route by the aid of a map and pictures of recognizable parts of the course. The rules for mandatory usage of cycling infrastructure were explained. Subjects were asked to ride in their personal everyday manner. They could wear none, an own or a provided helmet. To avoid additional influence the subjects' behavior, the decision to obey traffic rules was explicitly left to them, as well as lane choice. The subjects could take as much time as needed to familiarize with the pedelec. Thereafter, each subject was asked to ride the given course twice, once with the motor turned off, and once with active motor assistance. The order of the two rides was altered per subject to counter effects of exhaustion and familiarization with the route. After each ride and in the end, further sections of the questionnaire were filled out. Out of 52 data sets acquired, one had to be dismissed due to inoperable measuring equipment, and one due to large deviations from the route. 45 hours of data and video material were considered suitable for further analysis.

ANALYSIS OF RIDING SPEED

The analysis of cycled speeds was conducted with focus on different road sections as well as different groups of subjects. Average speeds for each ride in total were calculated, excluding stops, for taking out a random factor introduced by the states of traffic lights. For detailed analysis, the course was split into sections with different characteristics, defined by geographical rectangles. All data values inside a specific rectangle were included in the calculation of corresponding average speeds.

Statistical Analysis

To verify a significant difference in average speeds between the rides with and without motor assistance on the various sections of the route, a statistical analysis was performed. A significance level of 0.05 was chosen. For 16 of the 18 cases (nine sections, cycled with and without motor assistance) the Lilliefors test was conducted, a normal distribution can be assumed for average speeds of the subjects. A double check of the results with the Kolmogorov-Smirnov test revealed for all cases that the null hypothesis (values are normally distributed) cannot be rejected. Given normally distributed values, a paired t-test was conducted to test the null hypothesis that the differences in both groups, rides with and without motor assistance, have the average value of 0. In this case, the hypothesis has to be rejected to imply a significant difference between the two groups. In the t-test, the differences between the two groups have to be normally distributed. This was again verified with the Lilliefors test. The t-test implies a rejection of the null hypothesis on all nine sections and for the route in whole. Therefore, a statistically significant difference in average speeds with and without motor assistance can be assumed. Because the first Lilliefors test implied in 2 of 18 cases that a normal distribution cannot be assumed, additionally the Wilcoxon rank sum test was conducted, it also suggests a significant difference between average speeds on rides with and without motor assistance.

Speeds on Different Road Sections

To regard different circumstances, as traffic density, slopes and state of the road surface, the route was divided into nine sections (fig. 2). Mean speeds with and without motor assistance, as well as their differences, were used in the analysis. It was found that the effect of the motor assistance on allowing higher speeds was boosted by inclines and roomy infrastructure with few obstacles and lowered by factors as high traffic density, blocked view and insufficiently designed cycling infrastructure. Detailed results are shown in table 1.

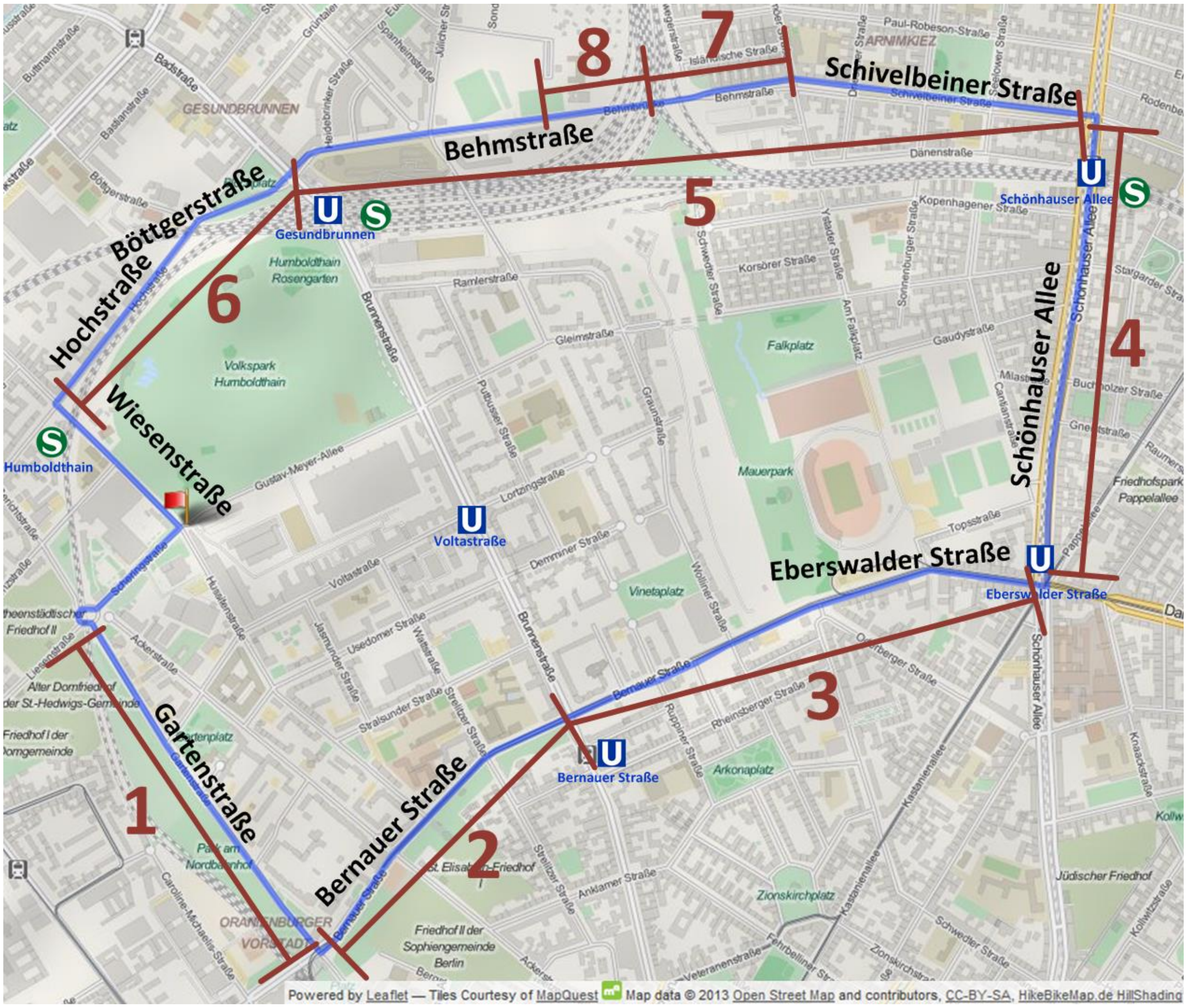

FIGURE 2 Sections of the Route

TABLE 1 Speed Differences Depending on Infrastructure

#	Length of section [km (mi)]	Speed average without motor assistance [km/h (mph)]	Speed average with motor assistance [km/h (mph)]	Speed difference [km/h (mph)]	Characteristics and annotations
1	0.9 (0.6)	25.0 (15.5)	26.6 (16.5)	1.6 (1.0)	Bike lane in good condition, smooth surface Clear view High speed even without motor assistance, may be caused by proximity to the starting point, where riders were still well rested
2	0.8 (0.5)	17.0 (10.5)	20.7 (12.8)	3.7 (2.3)	Bike path, narrow Incline

					Unevenly laid pavement slabs Pedestrians crossing or walking on bike path frequently Highly frequented by other cyclists High speed difference between rides with and without motor assistance because of the slope
3	1.2 (0.8)	20.7 (12.8)	24.0 (14.9)	3.3 (2.0)	Bike path Pedestrians crossing at tram stations High number of intersections, often with traffic lights Mostly clear view
4	1.1 (0.7)	19.8 (12.3)	21.4 (13.3)	1.6 (1.0)	Bike path, narrow Highly frequented by other cyclists Sharp bends Obstacles, as bus shelters and electric enclosures Pedestrians crossing at train station Speed rather limited by external factors than riders’ condition
5	1.9 (1.2)	21.5 (13.3)	24.8 (15.4)	3.4 (2.1)	First half of section on bike lane in good condition, smooth surface, second half on-road Less frequented by other cyclists Clear view Occasional vehicle parking on bike lane Includes steep incline and decline over a bridge
6	0.8 (0.5)	23.9 (14.8)	27.3 (16.9)	3.4 (2.1)	Bike lane in good condition, smooth surface Less frequented by other cyclists Slight decline Few side roads
7	0.4 (0.3)	19.5 (12.0)	25.8 (16.0)	6.3 (3.9)	Part of section 5, regarded on its own Incline of bridge Bike lane At this slope, the motor assistance had the highest impact on riding speed
8	0.3 (0.2)	28.3 (17.5)	31.4 (19.5)	3.1 (1.9)	Part of section 5 regarded on its own Decline of bridge Bike lane Even though motor assistance stops at 25 km/h (16 mph) and most riders were faster on this section, a difference in speed can be seen because of the more rested driver state with motor assistance and the higher initial speed at the peak
9	1.2 (0.8)	21.0 (13.0)	23.5 (14.6)	2.5 (1.6)	Section 5, regarded without the incline and decline over the bridge Bike line in good condition, smooth surface
All	7.5 (4.7)	19.8 (12.3)	22.5 (14.0)	2.7 (1.7)	

Speeds of Different Groups of Subjects

The increase in speed provided by the motor assistance is higher for slower subjects than for the faster ones. A reason for this is the limitation of the motor assistance to speeds below 25 km/h (16 mph). Faster riders only benefit when accelerating after stops or obstacles. For the 22 subjects with an average speed below 19 km/h (12 mph) without motor assistance, the speed increased by 3.8 km/h (2.4 mph) in average, for the faster riders just by 1.8 km/h (1.1 mph). More detailed values can be seen in fig. 3.

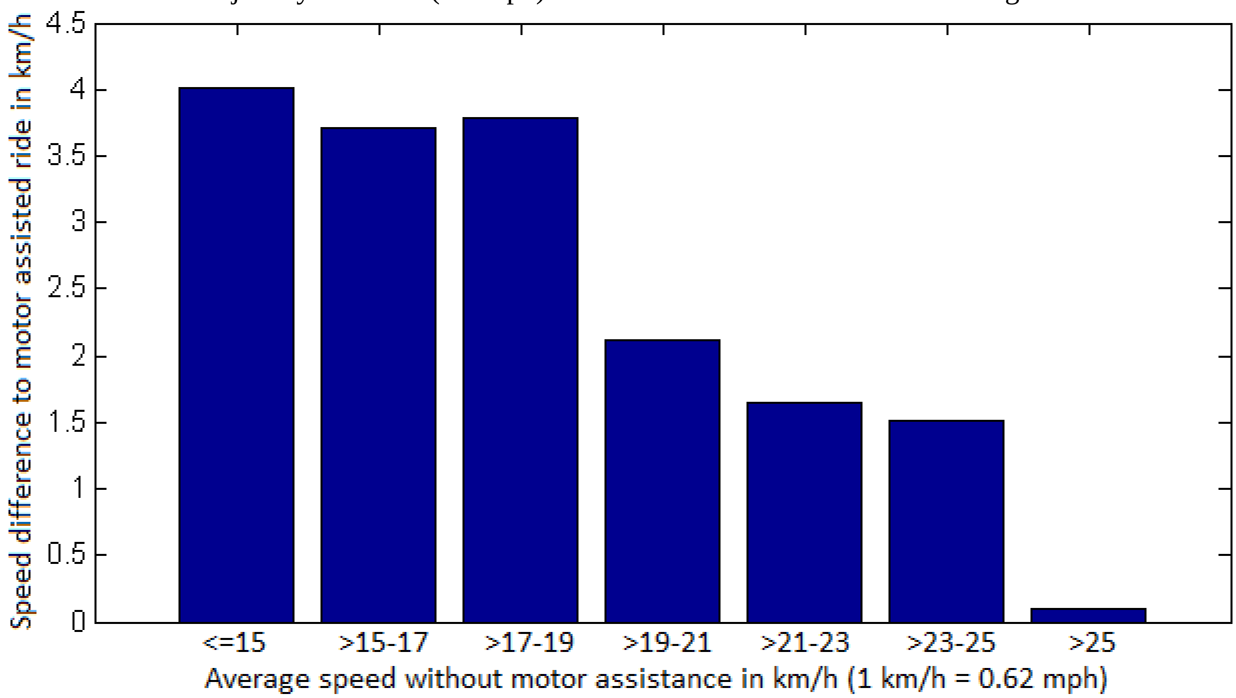

FIGURE 3 Speed difference depending on average speed. The subjects are sorted into classes spanning 2 km/h (1.2 mph) in the average speed on the ride without motor assistance. The y-axis represents the difference in speed compared to the motor assisted rides.

Influence of the Order of Rides

It was assumed that the order of the rides has an influence on average speeds. A second ride could be faster, because of better knowledge of the route and experience on the vehicle, or slower because of extortion. The median of average speeds of the first motor-assisted rides is 0.5 km/h (0.3 mph) higher than for the second rides. For the rides without motor assistance, it is 1.5 km/h (0.9 mph) lower. A statistical analysis with the Mann-Whitney U test was conducted, providing no proof for an influence of the order of rides on the average speeds.

ANALYSIS OF VIDEO DATA

In the Australian “Naturalistic Cycling Study”, two accidents and 6 near accidents occurred in 127 hours (*4*). A number of accidents and near accidents interpretable under statistical aspects could therefore not be anticipated in the 45 hours of video collected in this study. The use of existing accident categorization systems is not applicable. Therefore, a categorization which includes less intensive interactions with other traffic participants was developed to get a reasonable data pool. Incidents were sorted into seven categories, ranging from 0: no interaction to 6: accident. The focus was on the subjects themselves, they had to be active in the situation. A catalogue covering all possible occurrences would have been too comprehensive. Instead, examples for the different categories were set, all incidents were classified correspondingly.

The categories and examples are:

0: No interaction.

- Another cyclist rides on the same bike path, but in opposite direction. The subject neither evades nor slows down.
- The subject overtakes other cyclists at a red light, rolling slowly
- The subject has changed from a bike lane onto the road for overtaking and, while still on the road, overtakes another vehicle

1: Slight interaction. This category contains moderate, non-spontaneous everyday maneuvers.

- The subject slows down by no more than 20% of his/her speed because of another traffic participant
- The subject overtakes on the bike path without any trouble
- The subject slightly evades to increase clearance to pedestrians walking parallel to the bike path

2: Stronger interaction. This category contains stronger everyday maneuvers.

- While overtaking, the subject has to slow down slightly
- The subject reduces speed by more than 20%, but less than 50%
- The subject conducts a lane change onto the sidewalk or road for overtaking

3: Strong interaction. This category contains everyday maneuvers with wide evasion or significant decrease in speed.

- Because of another traffic participant, the subject slows down by more than 50%
- The subject has to evade widely (over two lanes or over a separation onto a sidewalk)
- The subject has to react fast because of late recognition of an obstacle or an unexpected maneuver of another traffic participant

4: Very strong interaction. A sudden and strong reaction of the subject is required.

- At an intersection, the driver of a vehicle required to give way overlooks the subject and pulls out. The subject has to break and/or evade immediately

5: Near accident. With a slightly different constellation, an accident would happene in this situation.

6: Accident.

- At contact between the subject and another traffic participant, kinetic energy is exchanged
- The subject falls down

For analysis of overtaking maneuvers, the results and categories of the video analysis were used. All events related to overtaking were extracted and assigned to slow and fast riders. Fast riders were defined by speed above the average of 19.8 km/h (12.3 mph) on the ride without motor assistance. No categories higher than 3 had been assigned. Categories 0 and 3 only contain 15 cases each for all subjects together. This was not sufficient for a significant conclusion. The cases are not regarded separately.

The use of the motor assistance resulted in an increase by 50% in overtaking maneuvers and therefore potentially dangerous situations. For the fast riders, the increase was only by 9%, for slow riders, on the other hand, the number of overtaking maneuvers doubled opposed to rides without motor assistance. Detailed results are shown in table 2.

TABLE 2 Number of Overtaking Maneuvers by Categories

	Category 1	Category 2	Categories 0 to 3
“slow”, without motor assistance	53	17	75
“slow”, with motor assistance	82	72	160
Difference	+ 55%	+324%	+113%

“fast”, without motor assistance “fast”, with motor assistance Difference	69 79 + 14%	50 54 + 8%	130 141 + 9%
Overall difference	+ 32%	+ 88%	+ 47%

The minor effect for the fast riders could be expected: With their high speed without motor assistance, the number of overtaking maneuvers was already on a high level, the slightly higher speed with motor assistance had no significant effect. For the slow riders, the situation is different: They highly profited from the motor assistance, and a much higher number of cyclists had been overtaken by them instead of just a few. The increase is prominent in category 2: The group of slow riders generally contains unexperienced cyclists for which overtaking was no routine.

SELF-EVALUATION OF SUBJECTS

The self-evaluation was done with aid of the questionnaire.

Cycling Experience

In the questionnaire, subjects were asked to assess their experience on riding a bike in urban traffic. Five possible answers were given (the translation from German may not reproduce the grading accurately):

1. I’m insecure/strongly challenged
2. I’m experienced, but some situations unsettle me
3. I’m well fit into Berlin traffic situation
4. I’m very experienced and can anticipate actions of other traffic participants
5. I can’t assess this

The answers were compared to the average speeds reached on the ride without motor assistance. It showed that subjects who said to be insecure were in average slower than the ones who claimed to be experienced. The Mann-Whitney U test was used on the average speeds of subjects in each of the four valid categories, revealing a significant difference to the values of each subsequent category. For the difference in speed between the rides with and without motor assistance, no statistically relevant dependence could be found.

Style of Cycling

Subjects were asked about their style of everyday cycling in the questionnaire. The following options were given:

1. I’m an unhurried rider
2. I’m trying to be efficient, but not to sweat
3. I’m a speedy rider
4. I’m riding fast/ambitious, yet defensive
5. I’m riding fast/ambitious and offensive
6. I can’t assess this

The answers to this question were compared to the average speed on the ride without motor assistance. The self-evaluation shows to correlate with the achieved speed. Equivalent to the test of significance for the cycling experience, the style of cycling was tested. The null hypothesis of medians in all categories being the same could be rejected in this case, too. Again, for the differences in speed between rides with and without motor assistance no correlation could be proven, yet a tendency to smaller differences can be seen for ambitious cyclists.

DISCUSSION

Comparison with Results of Other Studies

As mentioned above, a study with similar focus was conducted in the Netherlands. (9) Differences in speed between pedelecs and conventional bicycles were regarded. On a straight section of the route, a bicycle path outside the town, the younger one of the two age groups rode an average speed of 19.3 km/h (12 mph) on a bicycle, and 3.7 km/h (2.3 mph) faster on a pedelec. The comparable section 5 in the Berlin study, frequented by a low number of other traffic participants, was almost straight and only disrupted by few intersections. An average speed of 21.5 km/h (13.4 mph) was reached, with a difference of 3.4 km/h (2.1 mph) to the ride with motor assistance. With an average of 29 years, the Berlin subjects are 9 years below the Dutch average of 38 years in the younger group. This difference in age can explain the speed differences between the two studies. The speed gained with motor assistance in the two studies matches. It was 0.34 km/h (0.21 mph) higher in the Netherlands than in Berlin. A possible explanation for this slight deviation may be found in the use of a heavy pedelec with deactivated motor instead of a conventional bicycle in Berlin.

Transferability of the Results

The field study was conducted on a rather flat topology. The advantages of pedelecs at slopes are not as relevant as in hilly areas. Strong winds, as they occur on the coast line, are rare in Berlin. It can be assumed that pedelecs have a greater influence on the riding speed in areas with more adverse conditions for cyclists.

The group of test subjects is not representative for pedelec riders. Most subjects were below 30 years of age. For velobiz.de, which claims to be a specialized portal for the bicycle industry, a study was conducted in Germany regarding the ages of e-bike buyers. It was found out that 15% of e-bike buyers were between 18 and 35 years of age, 45% between 35 and 50, 30% between 50 and 65, and 10% over 65. An increase in the ratio of e-bike buyers below 50 years of age by 10% was found between 2010 and 2012. (*11*) Reliable statistics about the age of users of e-bikes are hard to come by, but these numbers indicate that the average e-bike user is older than the average participant in this study.

Use of a Pedelec Instead of a Bicycle

Instead of a bicycle, the pedelec, with the motor turned off, was used. In comparison to a conventional bicycle, it is heavier, and the center of gravity is higher. This may result in slightly longer ways for evading and stopping. An advantage of using the same vehicle was given by the exact same geometry on both rides, an influence of the body position on reached speeds is therefore excluded. Also, the vehicle didn’t have to be exchanged in mid test, and measuring equipment didn’t have to be obtained twice and calibrated between two vehicles.

Difficulties in Field Test and Analysis

Speed Measurement

For speed measuring, GPS data and acceleration data in driving direction was available, as well as a speed data channel provided by the data logger, also based on GPS. Position data has limitations for acquiring a reliable speed. Because of noise, the data has to be smoothed, which leads to loss in accuracy. Further issues occur through deviations from the actual route. In extreme cases, these were up to 250 m (820 ft). In street canyons, under bridges and near a train viaduct, the determined position was often inaccurate. For sections where no signal can be received, values were interpolated, which is problematic for longer down times. The use of a helical antenna instead of the patch antenna may prevent multipath and increase accuracy especially in street canyons. The use of a speed meter is recommended for further studies.

Video Analysis

Shaking from rolling over cobbled pavement, light changes and high contrasts, lens flare, water drops, turned cameras and low resolution of the videos were factors complicating analysis. The high number of cameras proved to be useful, as a slight redundancy was given.

Another problem was the assessment of situations: In some cases, the occurrences seemed more or less dramatic in the video than they were experienced by the cyclists. Interviewing them during video analysis can help to compare apparent and subjective intensity of danger.

Analysis of video data is time consuming. For this study, the time invested was approximately twice the running time. If a field experiment is planned on a larger scale, video analysis may not be possible with only one analyst anymore. A possibility to reduce the work is to concentrate on relevant events. They may be marked in the data sets with a push button activated by the subjects, as done in e-bikeSAFE study. (7). A further possibility is a diary or questionnaire in which the subjects keep record of the occurrences, including time and place.

Automatic search for dangerous situations in the data sets is difficult to accomplish. If a cyclist prevents an accident by accelerating to move out of the danger zone, this is hard to detect by algorithms. Low thresholds result in many false positives, which have to be sorted out manually. (*12*) It is difficult to distinct between normal maneuvers from an aggressively riding cyclist in normal situations and a dangerous situation. A strong deceleration on a car cutting the cyclist's right of way may indicate a dangerous situation for an inexperienced rider who had to break spontaneously, the experienced rider, however, may have noticed the car as a possible hazard long before and was ready to break in a controlled manner in the last possible moment.

Automated video processing is another option. The complexity is high. Objects have to be reliably recognized and classified, positioned and parameterized. Linking them to a dynamic model system may be useful.

Adjustment of the Pedelec to the Subjects

The frame size of the pedelec is a compromise. For very big or small participants, the saddle could not be positioned in a satisfactory manner. All intended subjects could ride in the test, but especially the small participants had slight problems in handling the vehicle.

Experience of the Subjects in Riding E-Bikes

None of the subjects was an experienced e-bike user, for 37 of the 52 participants it even was the first ride on such vehicle. It was not verified whether the familiarization rides conducted on the compound were sufficient. For further research, it is recommended to recruit everyday users of e-bikes. Some participants said to not ride a bicycle or e-bike in their routine. These people are not relevant in a representative group of cyclists.

Deviations from the Route

Of the 52 subjects, six took one wrong turn, and one lost his way four times. Because of the low number and small extent of the deviations, no explicit measure was taken in the analysis. The deviations of one subject from the route were extensive in a way that his data set was excluded from further analysis.

Data Logger

The sampling rate of the data logger is 10 Hz. 100 Hz are estimated to be adequate for derivation of acceleration profiles from speed data for analysis of dynamics.

Data from acceleration sensor

The data collected from the acceleration sensor is noisy. Because of the low acceleration characteristics on a bicycle, the signal is hard to extract. Filtering proved to be difficult because of the low sampling frequency. Use of this data for detection of possibly dangerous situations is very limited.

Naturalistic Cycling

For studies with stronger focus on naturalistic cycling, the measuring equipment has to be protected from theft and weather influences to be usable in everyday cycling. Operation by the subjects should be simple and fail safe.

The methodology applied for this study has limitations for observing cyclists in their natural behavior. The route was pre-determined. In consequence, personal preferences of the participants, e.g. traffic density, availability of bicycle infrastructure, condition of the road surface or the surroundings were therefore excluded. The pedelec used for the study did not comply with the individual needs of all riders. Some may prefer more sportive vehicles or different frame geometry and size.

It is not clear whether the subjects showed their natural behavior. In the 100-Car Naturalistic Driving Study, it was observed, that subjects were very careful on their first ride in an instrumented vehicle. If the effect wore off after just five minutes or after one hour could not be determined, an hour is assumed though. (*3, page 217*) In the questionnaire, nine of the 52 subjects of this study said they felt being monitored. Five subjects said they would have conducted more misdemeanors without being watched by the cameras. 13 subjects reported they were stimulated by the measuring equipment. One subject said to have executed more shoulder checks than usual, another one said to stay in the saddle against his habit when accelerating to stay in the field of view of the camera.

In sum, the limitations in regard of naturalistic cycling helped to provide better comparability between the different subjects. The two rides with and without motor assistance were conducted subsequently, so that circumstances, as weather, traffic density and condition of the road didn't change much for individual participants.

Questionnaire

The open questions about problems with other traffic participants proved to be very useful to identify the situations experienced as critical by the subjects. For further field tests, it is recommended to let the subjects rate the incidents to identify whether it was critical or just disturbing.

CONCLUSIONS

The methodology used in this study is, despite small inconveniences, suitable to work out differences between bicycle and pedelec use.

Significant differences were found in the riding speed: With a pedelec, riders are approximately 3 km/h (1.9 mph) faster than on a conventional bicycle. With good infrastructure, the difference is higher than with bad infrastructure, which is distinguished by blocked views, sharp turns, narrowness, crossings of other traffic participants and uneven surface. For efficient riding, adequate infrastructure is required. This can be achieved with sufficient space for overtaking and evading, smooth surface and clear views. Differences between rides with and without motor assistance also showed up in the number of overtaking maneuvers. Slow riders doubled their number of overtaking maneuvers compared to the ride without motor assistance. For fast riders, the increase was just by 9%. With the number of overtaking maneuvers the number of potentially dangerous situations rises, especially for the inexperienced riders. To support an expedient use of pedelecs, the infrastructure has to be upgraded, providing enough space for evading.

REFERENCES

1. Zahlen - Daten - Fakten zum Fahrradmarkt in Deutschland. *ZIV press conference on March 21st 2012*. Zweirad-Industrie-Verband e.V. , Berlin, 2012.
2. Dingus, T. A., S. G. Klauer, V. L. Neale, A. Petersen, S. E. Lee, J. D. Sudweeks, M. A. Perez, J. Hankey, D. J. Ramsey, S. Gupta, C. Bucher, Z. R. Doerzaph, J. Jermeland, and R. R. Knipling. *The 100-Car Naturalistic Driving Study: Phase II – Results of the 100-Car Field Experiment.* Blacksburg, USA, 2006. http://www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/Driver%20Distraction/100CarMain.pdf
3. Johnson, M., J. Charlton, and J. Oxley. The application of a naturalistic driving method to investigate on-road cyclist behaviour: A feasibility study. In *Road & Transport Research, 19(2):33–41*, 2010.
4. Johnson, M., J. Charlton, J. Oxley, and S. Newstead. *Naturalistic Cycling Study - Identifying Risk Factors for On-Road Commuter Cyclists*, Melbourne, Australia, 2010.
5. Gustafsson, L., and J. Archer. A naturalistic study of commuter cyclists in the greater Stockholm area. *Accident Analysis & Prevention, 58:286–298*, doi:10.1016/j.aap.2012.06.004, Elsevier, 2013. http://dx.doi.org/10.1016/j.aap.2012.06.004
6. Dozza, M., J. Werneke, and A. Fernandez. *Piloting the Naturalistic Methodology on Bicycles*. 2012. http://www.fietsberaad.nl/library/repository/bestanden/121107_Dozza_Piloting-the-naturalistic-methodology-on-bicycles_2.pdf.
7. Dozza, M., J. Werneke, and M. Mackenzie. e–BikeSAFE: *A Naturalistic Cycling Study to Understand how Electrical Bicycles Change Cycling Behaviour and Influence Safety*. Helmond, The Netherlands, 2013.
8. Gehlert, T., M. Kühn, K. Schleinitz, T. Petzoldt, S. Schwanitz, and R. Gerike. *The German Pedelec Naturalistic Cycling Study: Study Design and First Experiences: Proceedings*. International Cycling Safety Conference, Helmond, The Netherlands, 2012. http://www.fietsberaad.nl/library/repository/bestanden/121107_Gehlert_the-german-pedelec-naturalistic-cycling-study.pdf.
9. Twisk, D. A. M., M. Boele, W. P. V, M. Christoph, R. Sikkema, R. Remij, and A. L. Schwab. *Preliminary results from a field experiment on e-bike safety: speed choice and mental workload for middle-aged and elderly cyclists: Proceedings*, International Cycling Safety Conference, Helmond, The Netherlands, 2013.
10. *Video VBOX Pro Datasheet*. Racelogic Ltd., 1st edition, Buckingham, Great Britain, 2012.
11. *Studie: E-Bike-Käufer werden jünger*. eBikeNews, 2013. http://www.ebike-news.de/studie-e-bike-kaeufer-werden-juenger/5858/. Accessed Feb.27, 2014.
12. González, N.P. *Recognizing safety-critical events from naturalistic driving data*. PhD thesis, Chalmers University of Technology, Gothenburg, Sweden, 2011.